Applied Research

The rapid growth of telecommunications over the last 40 years has caused crowding in the radio spectrum. New technology has required a new understanding of radio wave behavior in all parts of the radio spectrum. The Institute studies the lowest frequencies to the highest frequencies in use.

This work extends ITS' expert understanding of the ways that radio signal propagation is affected by the earth's surface, the atmosphere, and the ionosphere. It is resulting in new propagation models for the broadband signals used in some of the new radio systems. Other efforts are increasing our understanding of the propagation of millimeter-wave frequencies, providing a large band for future expansion of new radio communication services.

The Institute's historical involvement in radio-wave research and propagation prediction development provides a substantial knowledge base for the development of state-of-the-art telecommunication systems. ITS transfers this technology to both public and private users, where knowledge is transformed into new products and new opportunities.

Areas of Emphasis

Cooperative Research with Industry

The Institute engages in technology transfer through cooperative research with industry. Projects are funded by US WEST Advanced Technologies, Inc. (US WEST), Telesis Technologies Laboratory (TTL), Integrator Corp., Motorola, Inc., the American Automobile Manufacturers Association, and Hewlett-Packard Co. (HP).

Advanced Radio Research

The Institute conducts research of digital radio receivers with the ultimate goal of digitizing the RF signal at the output of the receive antenna. This technology will become increasingly important as mobile cellular, satellite, and personal communications services radio systems are developed. This project is funded by NTIA.

Millimeter-wave Research

The Institute conducts research on the millimeter-wave radio propagation channel. The results of the research enable industry to develop and deploy LMDS systems. Projects are funded by NTIA, HP, and TTL.

Wireless Propagation Research

The Institute studies radio propagation channels that will be employed in new wireless communication technologies such as personal communications services. This knowledge will aid both Government and industry as these systems are developed and deployed. Projects are funded by NTIA, US WEST, Motorola, Inc., and HP.

Wireless System Modeling and Simulation

The Institute conducts software simulation of wireless systems to predict performance for new radio systems. Projects are funded by NTIA and the National Security Agency.

HF Channel Modeling and Simulation

The Institute contributes to HF channel modeling and simulation that enables network users and administrators to optimize network utilization. Projects are funded by NTIA and the National Communications System.

Advanced Radar Research

The Institute studies the effect of the radio propagation channel on many radar applications. This knowledge allows simulation of the total system in order to predict radar performance. The project is funded by NTIA and the National Center for Atmospheric Research.

Cooperative Research with Industry

Outputs

- Simulation model of broadband millimeter-wave propagation to assist in the evaluation, planning, and deployment of local multipoint distribution services.
- Models of broadband radio propagation channels that will be employed in wireless technologies for a rural community communications infrastructure.
- Continuous wave and wideband measurements at 28-30 GHz for characterization of broadband propagation in urban and suburban environments.

The Technology Transfer Act of 1986, as amended, allows Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties. The law was passed in order to provide laboratories with clear legal authority to enter into these arrangements and thus encourage technology transfer from Federal laboratories to the private sector. Under this Act a cooperative research and development agreement (CRADA) can be implemented that protects proprietary information, grants patent rights, and provides for user licenses to corporations, while allowing Government expertise and facilities to be applied to interests in the private sector.

ITS is actively engaged in technology transfer and commercialization efforts by fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities. ITS has participated for a number of years in CRADAs with private sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. Research has been conducted under agreements with Bell South Enterprises; Telesis Technology Laboratory (TTL); US WEST Advanced Technologies (US WEST); Bell Atlantic Mobile Systems; GTE Laboratories, Inc.; US WEST New Vector Group; General Electric Company; Motorola, Inc. (Motorola); Hewlett-Packard Company (HP); Integrator Corp.; and the American Automobile Manufacturers Association (AAMA). Not only does the private industry partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do.

Much of the Institute's work in personal communications services (PCS) has been accomplished through CRADAs. Under CRADAs with Motorola and US WEST, ITS has conducted field measurements to characterize the PCS radio channel in a variety of urban and suburban environments. The data obtained from these field measurements is used to validate simulation models that the Institute has developed. As part of the CRADA with US WEST, ITS served as a neutral independent observer as the Joint Technical Committee on Wireless Access (JTC) conducted field trials of proposed PCS air-interface standards in the Boulder Industry Test Bed. Trials were completed on six PCS air-interface standards and the results have been reported to the JTC.

ITS has entered into a CRADA with AAMA to collect field data that will define the electromagnetic environment at specific locations in the United States. As electronic devices proliferate, it becomes important for the motor vehicle industry to have knowledge of the electromagnetic environment in which vehicular electronics will operate. This knowledge is essential to the development of future automotive electronics.

ITS has developed a PCS/local multipoint distribution service (LMDS) propagation model, within a geographic information system, to predict line-of-sight coverage of the PCS/LMDS signals (see the Figure). As part of a CRADA with Integrator Corp., ITS will use a terrain database with this PCS/LMDS model to produce signal coverage patterns for rural communities; Integrator Corp. will investigate the feasibility of wireless local or metropolitan area network technology as the basis for a rural community communications infrastructure.

ITS has been a premier laboratory for millimeter-wave research for two decades. Now ITS is applying this unique expertise while researching radio propagation considerations for LMDS. ITS has CRADAs with TTL and HP for LMDS research. Under the current agreements, ITS is developing propagation models for the LMDS channel, making field measurements to characterize radio frequency propaga-

PCS/LMDS line-of-sight coverage for Boulder, Colorado.

tion of an LMDS system, and developing a three-dimensional signal coverage map of the area of interest for LMDS transmission. The field measurements use an innovative impulse response measurement system called a digital sampling channel probe. This system allows the measurement of the complex-valued radio channel impulse response, and is ideal for making outdoor impulse response measurements. The three-dimensional signal coverage map is generated using the PCS/LMDS propagation model in conjunction with a digital elevation model.

Cooperative research with private industry has helped ITS accomplish its mission to support industry's productivity and competitiveness by providing insight into industry needs. This has led to adjustments in the focus and direction of other Institute programs to improve their effectiveness and value.

ITS is interested in assisting private industry in all areas of telecommunications. The pages of this technical progress report reveal many technological capabilities that may be of value to various private sector organizations. Such organizations are encouraged to contact ITS if they believe that ITS may have technology that would be useful to them.

Because of the commercial importance of many new emerging telecommunication technologies including PCS, wireless local area networks, digital broadcasting, LMDS, the National Information Infrastructure, and intelligent transportation systems, ITS plans to vigorously pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies. In addition, ITS continues to commit substantial resources of its own to the development of these new technologies and standards.

Recent Publications

R. Dalke, G. Hufford, and R. Ketchum, "Radio propagation considerations for local multipoint distribution systems," NTIA Report 96-331, Aug. 1996.

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Outputs

- Journal article on analog-to-digital converters for radio receiver applications.
- NTIA Report on RF and IF digitization in radio receivers.
- Presentation on direct digitization at the RF in radio receivers at the 1996 National Radio Science Meeting.

As advances in technology provide increasingly faster and less expensive digital hardware, more of the traditionally analog functions of a radio receiver will be replaced with software or digital hardware. The final goal for radio receiver design is to digitize directly the RF signal at the output of the receive antenna and therefore implement all receiver functions in either software or digital hardware. Figure 1 shows an example of this ideal receiver employing direct digitization at the RF.

The trend in receiver design is evolving toward this goal of the ideal receiver by incorporating digitization closer and closer to the receive antenna for systems at increasingly higher frequencies and wider bandwidths. While radio receivers with analog RF front-ends using digitization at baseband have been around for many years, the popularity of receivers using digitization at the IF is increasing rapidly. Digitization at the RF, without an initial downconversion, currently is used in only very restricted applications where the maximum frequency is relatively low and/or the spurious-free dynamic range (SFDR) requirements are relatively low.

There is keen interest in replacing analog hardware with digital signal processing in radio receivers for several reasons. One reason is the potential for the reduction in product development time since changes can be implemented in software instead of altering the hardware. Digital technology can offer a more ideal performance for implementing signal-processing functions. The repeatability and temperature stability can be substantially better. Functions that are not implementable in analog hardware (such as finite impulse response filters) can be implemented in software. The tuning or “tweaking” typically required in an analog implementation to achieve the desired performance is not required for digitally implemented signal-processing functions. Cost-effective multipurpose radios can be designed to allow reception of different modulation types and bandwidths simply by changing the software that controls the radio. Finally, there can be significant cost savings in implementing the receiver.

The Institute initiated a general study of the theory, concepts, and practical hardware limitations of radio receivers that use digitization at the RF or IF. This was the first phase of an effort to investigate the impact of radios that use digitization at the RF or IF on management of the Federal radio spectrum. This initial study examined the key factors in radio receivers that use digitization at the RF or IF: analog-to-digital conversion and digital signal processing. (While not explored in this study, for applica-

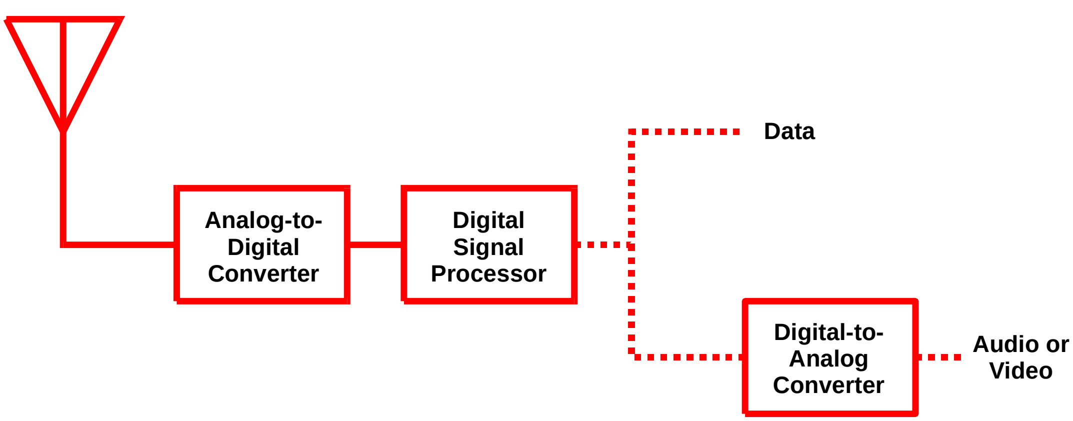

Figure 1. Ideal receiver employing direct digitization at the RF.

tions requiring analog output, such as voice, digital-to-analog conversion also is a factor.)

Results of this study revealed many interesting and important findings. Digitization at the RF, in general, requires some type of bandlimiting (filtering) and amplification before the actual digitization takes place. The required amount of filtering and amplification is application-specific. While analog-to-digital converter (ADC) performance is improving rapidly, Figure 2 shows that there is a tradeoff: high sampling rates or high resolution can be achieved, but not both simultaneously. Therefore, the high sampling rate ADCs required for wide bandwidth applications may not have sufficient SFDR. Digitization at the RF now is being considered for satellite receivers since a large SFDR is not a necessity, very high sampling rate ADCs already exist, and even faster ADCs are being developed. For receiver applications requiring a large SFDR, such as HF communications, digitization at the IF is currently a more practical option.

The study concluded that digital signal processors may present an even greater limitation than ADCs in radio receivers using digitization at the RF or IF. The speed, size, and cost of these processors are important for a particular radio receiver application. Examples of the processing speed of different processing platforms are shown in Figure 3. The requirement for real-time operation for many radio receivers places a heavy burden on these processors. The amount of time required for signal processing is a function of the bandwidth of the signal, the speed of the processor, and the number and complexity of the algorithms required to perform the needed radio receiver functions.

Various quantization techniques, nonlinear compression devices, postdigitization algorithms for improving dynamic range, sampling downconverters, and specialized integrated circuits were investigated in the study since they are expected to be useful in the development of radio receivers employing digitization at the RF or IF. Several examples of radio receivers (currently existing or in development) that use digitization at the RF or IF were identified in the study.

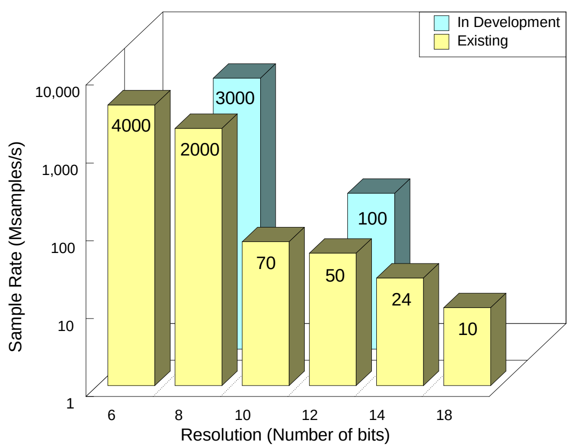

Figure 2. Examples of high-speed ADC performance.

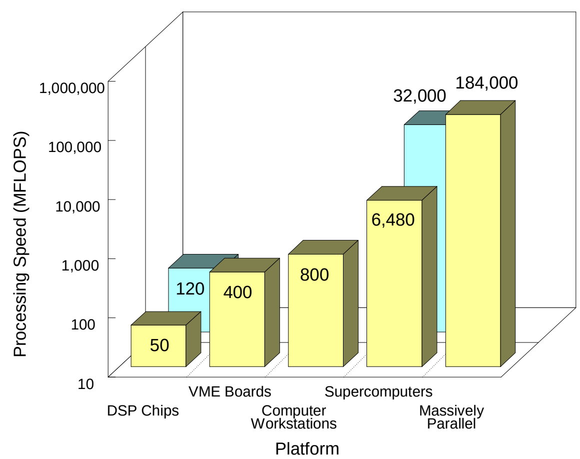

Figure 3. Examples of processing technology.

Recent Publications

J.A. Wepman and J.R. Hoffman, “RF and IF digitization in radio receivers: theory, concepts, and examples,” NTIA Report 96-328, Mar. 1996.

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Millimeter-wave Research

Outputs

- Channel measurements of local multipoint distribution service propagation.
- Millimeter-wave propagation channel models.
- Simulation of local multipoint distribution service performance, including the effects of nonlinear radio equipment, the propagation channel, and noise.

In the past few years, consideration has been given to the reallocation of frequencies in the extremely high frequency (EHF) band so that wireless video, voice, and data services could be made commercially available to consumers. The potential availability of spectrum for these “wireless” services has resulted in an increased commercial interest in propagation effects for millimeter waves. Of particular interest is the development of a wireless alternative to cable television and local exchange carrier offerings called local multipoint distribution services (LMDS). A clear understanding of the interplay between millimeter-wave propagation effects and methods proposed for the broadcast and reception of such services is essential to the development and implementation of LMDS.

For over two decades, ITS has been a leader in the study of propagation effects for millimeter waves. This work includes the development of measurement techniques; an extensive database of measured propagation effects such as multipath in urban and rural environments (including the effects of vegetation); and the development of analytical methods for prediction of atmospheric effects (e.g., attenuation and dispersion by absorption lines). Through cooperative research agreements, ITS is applying its technical expertise in millimeter waves to areas of commercial interest in the planning and development of LMDS.

There are several unanswered questions relating to radio propagation in urban and suburban environments that need further study to properly address the viability of LMDS for terrestrial digital broadcasts. As part of the millimeter-wave research efforts, ITS recently completed a comprehensive study of the LMDS radio propagation channel in a variety of suburban environments. This study included field measurements at 28.8 and 30.3 GHz, as well as a statistical analysis of the data and the development of propagation channel models. For this study, the millimeter-wave measurements were used to determine area coverage, multipath effects, time variations of the received power, excess path loss (relative to free space), signal depolarization, and the effects of variations in receiver height on area coverage for an LMDS broadcast cell.

The LMDS measurements were made using the ITS wideband probe (Violette, et al., 1983). A narrowband signal was used to make received power measurements over a large dynamic range with high sensitivity. The wideband signal provided 2-ns multipath resolution. In addition to calculating the area coverage and related parameters discussed above, the measured impulse response data was used to develop an appropriate time-varying radio channel model (tap delay line) that can be used in conjunction with the digital simulation models developed by ITS. An example of three-dimensional impulse responses resulting from this measurement program are shown in Figure 1.

The successful implementation of proposed terrestrial digital broadcast systems (e.g., television) requires an estimate of the expected bit error probabilities based on the various radio system components that will be implemented (e.g., modulation, coding, equalization, and nonlinear amplifier effects) and the radio propagation channel. Given the complex nature of both the radio system and the propagation channel, simulations are required to estimate bit error probabilities and service coverage areas. ITS has developed a computer simulation model that can be used to predict bit error probabilities as a function of the radio propagation channel, channel equalization, digital modulation methods, and radio system components (e.g., amplifiers and filters).

An important consideration in the implementation of broadband terrestrial broadcast using millimeter waves is the nonlinear effects of the transmitter amplifier. The traveling wave tube amplifier (TWTA) is a highly efficient broadband millimeter-wave amplifier and has been proposed for use in LMDS transmission systems. The nonlinear charac-

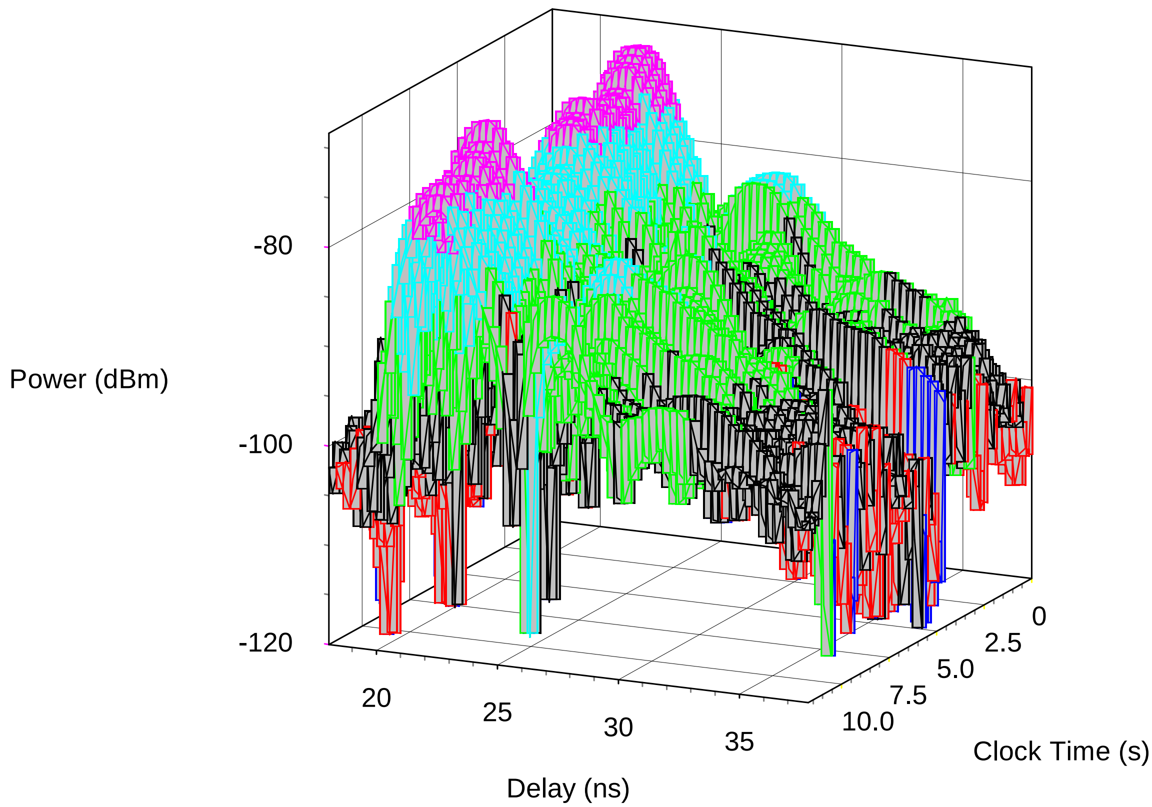

Figure 1. Measured three-dimensional impulse responses for moderate wideband channel.

teristics of this type of amplifier result in signal distortion which is due primarily to intermodulation. Using the ITS model, we can for example, predict how the TWTA affects symbol error probability for a variety of modulation methods. In Figure 2, the symbol error ratio is plotted as a function of input backoff (and carrier-to-intermodulation ratio; C/I) for 64 quadrature amplitude modulation (64QAM) and 64 trellis-coded modulation (64TCM). In this example, RF bandwidth = 7.2 MHz, transmitter filter rolloff = 50%, and three carriers have a guard band of 20%. The results indicate that trellis coding significantly reduces the symbol error ratio when the amplifier backoff is greater than 5 or 6 dB.

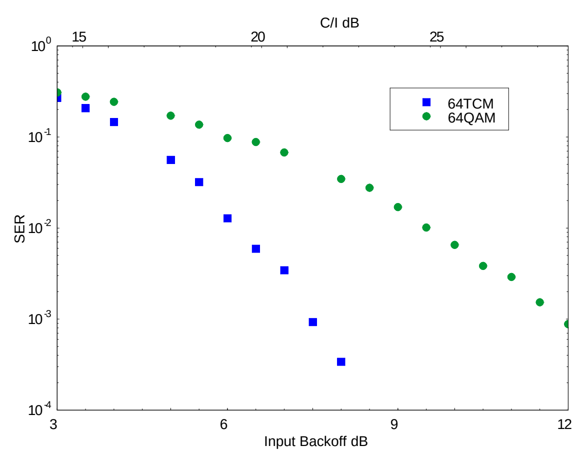

Figure 2. Simulated traveling wave tube amplifier nonlinear effects on the received symbol error ratio (SER) for 64QAM and 64TCM.

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Wireless Propagation Research

Outputs

- Indoor channel modeling.
- Impulse response prediction for an indoor propagation channel.
- Delay spread prediction of the multipath channel.

In designing wireless telecommunication systems, it is important to control the intersymbol interference (ISI), or more importantly, the bit error rate (BER). The ISI is related directly to the multipath phenomena resulting from objects such as walls, furniture, and people in the propagation path between the transmitter and receiver (Figure 1). The delay spread of the impulse response of the propagation channel is a measure of the multipath effects. The BER in most wireless systems is proportional to the square of the ratio of the delay spread to the symbol period. Therefore, in choosing the maximum data rates for a particular system, it is important to know the delay spread for the indoor environment where the system is to be deployed. The Institute is involved in several research efforts to estimate the impulse response and delay spread for indoor propagation channels.

The Institute has developed a geometric optics (or ray-tracing) model for calculating the impulse response of an indoor radio propagation channel. The mobile impulse response generator (MIRG) is implemented on a personal computer and calculates the impulse response of an ideal indoor channel. A recursive-imaging algorithm is used to find all possible rays with up to a specified number of wall, ceiling, and/or floor reflections. The plane wave Fresnel reflection coefficients are used to calculate the reflection of the rays that strike one of these surfaces. Typically, impulse responses generated using only five reflections provide a sufficient description for an indoor channel. However, the higher-bounce capability allows for the study of special cases, such as metallic rooms and anechoic chambers at fre-

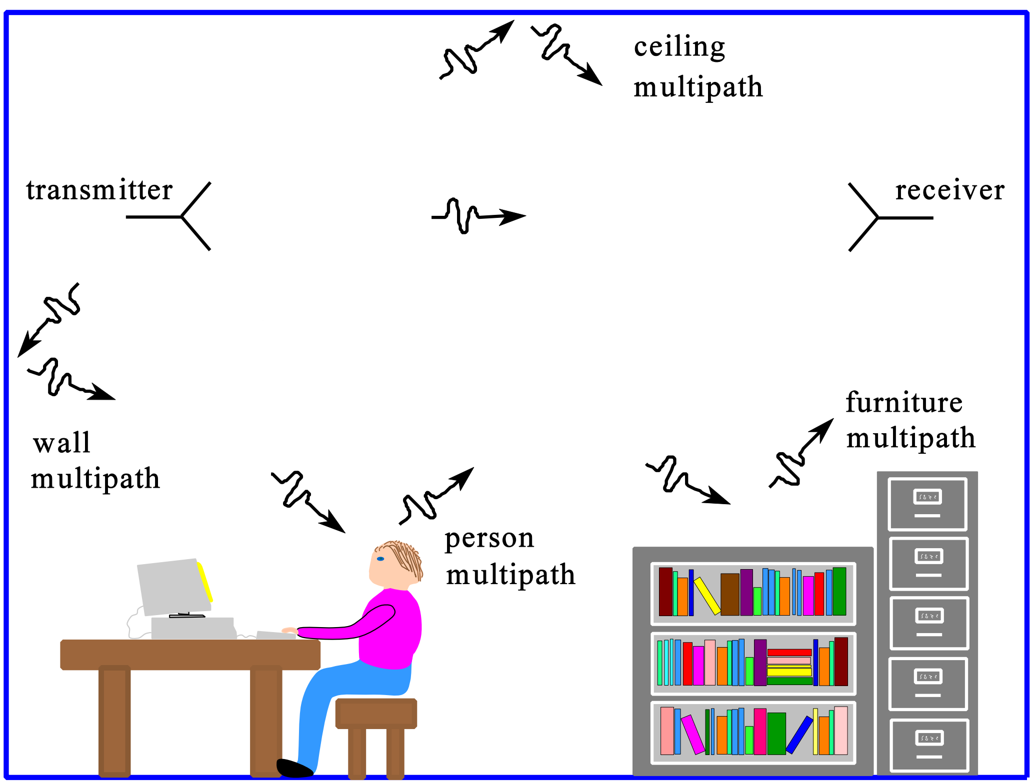

Figure 1. Illustration of multipath for an indoor propagation channel.

quencies below 80 MHz. The output of this model can be used easily as a channel model in radio system software simulation. Figure 2 shows the magnitude of the impulse response at one location in a room with a length of 12 m, a width of 8 m, and a height of 6 m.

The Institute also is investigating the use of a three-dimensional finite difference time domain (3D-FDTD) approximation to Maxwell's Curl Equations to determine the impulse response of the indoor channel. The advantage of this approach is that it is very accurate, and objects in the rooms can be incorporated easily. The disadvantage, however, is that this approach can be computationally intensive, requiring large amounts of computer memory and time. Different approaches for eliminating some of these pitfalls are currently under investigation.

While both the FDTD and the ray-tracing techniques are accurate, they can be very time-consuming. The Institute presently is developing a simplified model for calculating the impulse response and delay spread for the indoor channel. For years, the acoustic community has been estimating the decay rates (or reverberation time) of acoustic cavities in rooms, and recently these concepts have been used to analyze electromagnetic anechoic test chambers. By extending this work, it is possible to show that the average impulse response of a room can be given by very simple expressions. The parameters in this expression are the volume of the room, the surface area of the room, the amount of energy absorbed into the walls, the energy loss through doors and windows, and the energy absorbed into objects within the room. Once the impulse response is obtained, the delay spread can be calculated easily.

Preliminary results from this model are shown in Figures 2 and 3. Figure 2 compares the impulse response from the model to results obtained from MIRG; Figure 3 compares the results from this model to measured data. The advantage of this model is that it is based upon simple assumptions, such that the impulse response and delay spread can be calculated in a matter of seconds on a personal computer.

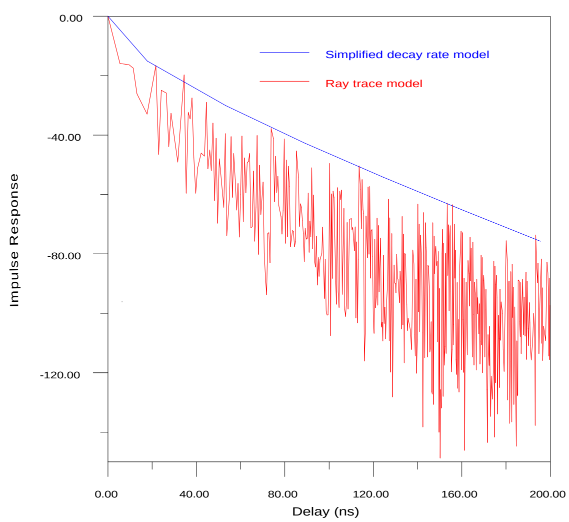

Figure 2. Comparison of the impulse response obtained from the mobile impulse response generator to the simplified decay rate model.

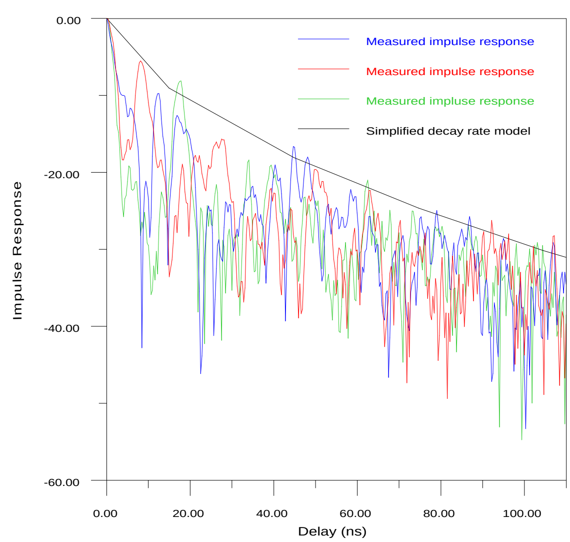

Figure 3. Comparison of the impulse response obtained from measurements to the simplified decay rate model.

Recent Publications

C.L. Holloway and E.F. Kuester, "Modeling semi-anechoic electromagnetic measurement chambers," *IEEE Trans. Electromagnetic Compatibility*, vol. 38, no. 1, pp. 79-84, 1996.

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Wireless System Modeling and Simulation

Outputs

- System simulation (modems, channel, and noise) software modules.
- Predicted bit error rate performance as a function of signal-to-noise ratio.
- Predicted speech and image quality using compression as a function of bit error rate and signal-to-noise ratio.

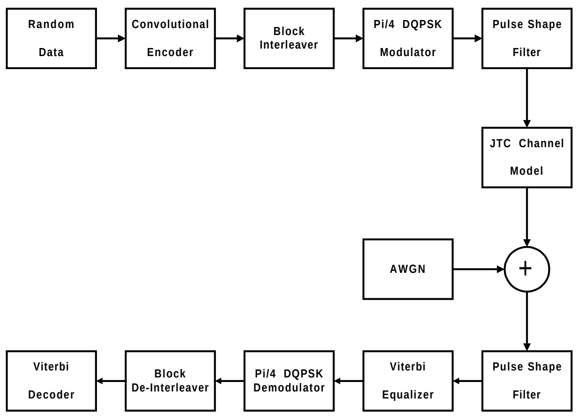
ITS has been conducting research of wireless systems for many years. Past efforts include radio, television, and radar channel propagation and impulse response measurement and modeling; software simulation of the channel for system performance prediction; hardware simulation of the channel for system hardware testing; and network performance prediction. Recent efforts have predicted system performance through software simulations of the system and channel for a variety of channels, modems, processing techniques, and sources. Channels include ionospheric, outdoor macrocell and microcell, and indoor microcell environments. Processing techniques such as compression, encryption, equalization, and channel coding have been used.

ITS has investigated the effects of multipath fading, noise sources, and cochannel interference on performance of land mobile radio, wireless private branch exchange, global system for mobile communications, IS54/136 personal communications services (PCS), wireless local area networks, and ionospheric high-frequency systems. Three types of channel distortion were used in the simulations: (1) time-varying multipath, (2) additive noise, and (3) cochannel interference. Sources include data, pulse-code modulation and voice-encoded speech, fax, uncompressed and discrete cosine transform (DCT)-compressed images, and automatic link establishment signals. Performance is described by bit error rate (BER), frame error rate, eye diagrams, in-phase/quadrature diagrams, character error rate, speech quality, and image quality.

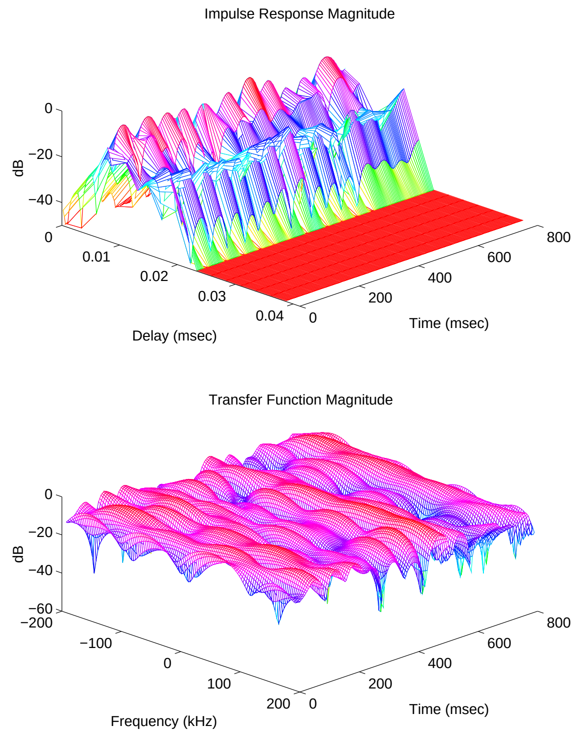
Implementation of the digital PCS standard IS54/136 is described in Figure (a) and was simulated to be operating at pedestrian speeds in an urban/suburban low-rise building and antenna environment described by Figure (b). These time-division multiple access (TDMA) systems are designed for the 1900-MHz frequency band and can operate in the bandwidth of a 30-kHz advanced mobile phone service (AMPS) channel. Compressed speech and image sources were transmitted by the B/4 DQPSK modem through a channel model derived from the Joint Technical Committee (JTC) air-interface standards that were proposed for PCS. The system employed a convolutional channel encoder and block interleaver, and a Viterbi equalizer and decoder. Figures (c) and (d) illustrate the predicted performance of this system.

Figure (b) describes the JTC channel C model characteristics in the time and frequency domain. It exhibits Doppler fading along the time axis (maximum Doppler frequency of 9.6 kHz) caused by the pedestrian velocity of 1.5 m/s and frequency-selective fading. Fading along the frequency axis corresponds to the coherence bandwidth of 106 kHz associated with the delay spread of 1500 ns specified in the 6 tap model. Doppler and frequency-selective fading and baud rate contribute to burst errors in the system. In addition, uncorrelated errors are caused by additive white Gaussian noise (AWGN). The fading effects of the channel are the primary error source beyond 20-dB signal-to-noise ratio (SNR) where the performance is channel limited.

Figure (c) demonstrates the channel-limiting effect on the BER performance. The AWGN curve shows how rapidly performance would improve if there were only random noise causing bit errors. Transmission of voice-coded speech through channel C at 30 dB SNR resulted in distortion corresponding to a quality class of 2.5 out of 5. This channel model is intended to represent worst case conditions for this environment. A topographic map image compressed and transmitted using the DCT coefficients resulted in a quality class of 3 out of 5 at 30 dB SNR. The resulting received image after decompression is shown in Figure (d). Block errors are observed due to channel fading, causing error burst lengths exceeding the correction capability of the channel coding. Predicted performance of wireless systems is used to compare proposed wireless standards, determine design specifications, and select deployment parameters of military and commercial systems.



(a)



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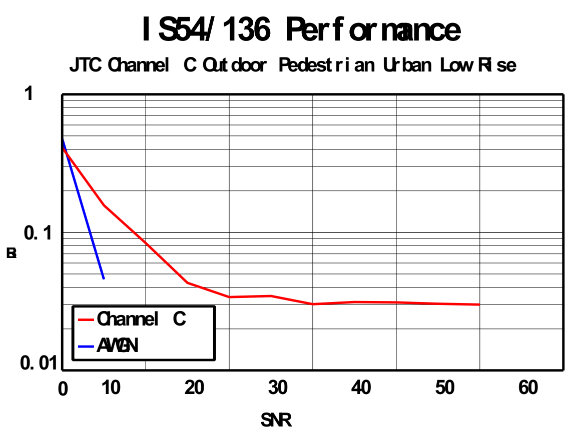
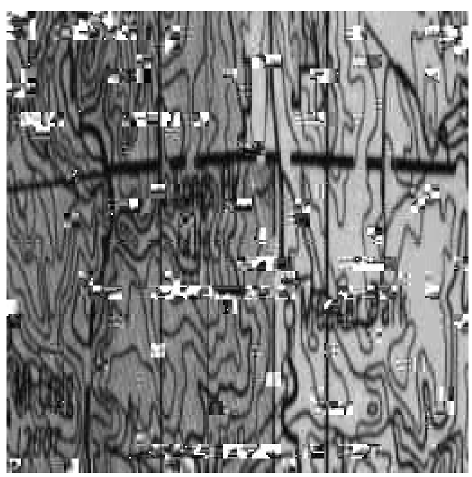


(c)



(d)

Performance of IS54/I36 PCS communicating over a JTC channel C model for worst conditions in an urban/suburban low-rise, low antenna environment: (a) simulation block diagram, (b) channel characteristics, (c) bit error performance, and (d) received image with a signal-to-noise ratio of 30 dB using discrete cosine transform compression.

Recent Publications

E.A. Quincy, R.J. Achatz, and M.Terada, “IS54/136 PCS performance prediction for standard JTC channels,” in *Proc. Wireless 1996 8th Internat. Conf.*, Calgary, Alberta, 1996, pp. 43-57.

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HF Channel Modeling and Simulation

Outputs

- Real-time wideband HF channel simulator.
- Radio Science and IEEE Transactions publications.
- Contributions to international HF standardization.

Channel simulators have long been accepted as an effective means for evaluating radio system performance. Advantages of using channel simulators in radio testing include repeatability, convenience, stationarity, availability, control of channel conditions, and relatively low cost. ITS has played a leading role in the development of simulators for HF communication channels for many years. In recent years, this work has been focused on the simulation of wideband (up to 1 MHz) HF channels. This work supports the development of national and international HF radio standards and the testing of prototype spread-spectrum HF radio equipment.

During FY 96, the Institute's wideband HF channel-modeling and simulation program had four primary goals. The first goal was to enhance the existing ITS-developed wideband HF channel simulator to permit the simulation of atmospheric, Gaussian, and impulsive noise. A commercially available waveform generator was integrated with the existing simulator to provide these new capabilities. The waveform generator is programmable, and thus has the flexibility to emulate realistic HF noise environments—including the complex environments specified in noise models developed in prior ITS work.

The second goal was to disseminate key program results in technical publications. Staff members submitted a technical paper describing the wideband HF noise and interference model to the journal *Radio Science*. A second paper, which provides a comprehensive summary of the Institute's research in wideband HF channel modeling and simulation, was accepted for publication in the *IEEE Transactions on Communications*. Several other technical papers, addressing particular aspects of wideband HF channel characterization, were initiated and will be submitted for publication early in FY 97.

The third goal of the FY 96 HF Channel Modeling and Simulation program was to make technical contributions to the development of international standards on HF communications. An existing International Radio Consultative Committee (CCIR) Report and associated International Telecommunication Union-Radiocommunication Sector (ITU-R) recommendation describe HF ionospheric channel simulators and their use (CCIR, 1990). The HF channel model specified in the CCIR Report was developed from a database consisting of 36 min of information collected on a single day on a single, 1300-km mid-latitude path under quiet ionospheric conditions. The valid bandwidths of the model were 2.5 kHz, 8 kHz, and 12 kHz for the three sample periods observed. The model assumes that delay dispersion is negligible. Although this narrowband model has been implemented widely and has proven to be quite useful, an enhanced model that accommodates wider bandwidths, additional propagation conditions, and more accurate representation of noise and interference is needed to properly assess advanced HF equipment. In FY 96, Institute engineers submitted a proposed U.S. contribution that defines such an enhanced model to U.S. ITU-R Working Party 9C. The contribution specifies (1) a new propagation model that emulates HF propagation conditions for either narrowband (a few kHz) or wideband (hundreds of kHz) channels; (2) an accurate noise and interference model for most operational HF environments; and (3) an architecture to implement those models in a real-time simulator. This contribution was approved by the U.S. Working Party and will be submitted to the corresponding international ITU-R Working Party at its January 1997 meeting.

A final goal of the HF Channel Modeling and Simulation program was to apply the Institute's wideband HF channel simulator in testing high-speed wideband HF modems. The simulator was used in the preliminary evaluation of a direct sequence spread-spectrum modem being developed for the Department of Defense. The test results showed that the high-speed modem could operate effectively over ionospheric paths; this supported a decision to advance the Department of Defense's research and development program towards full implementation. A block diagram and front panel photograph of the ITS-developed wideband HF simulator are provided in Figures 1 and 2, respectively.

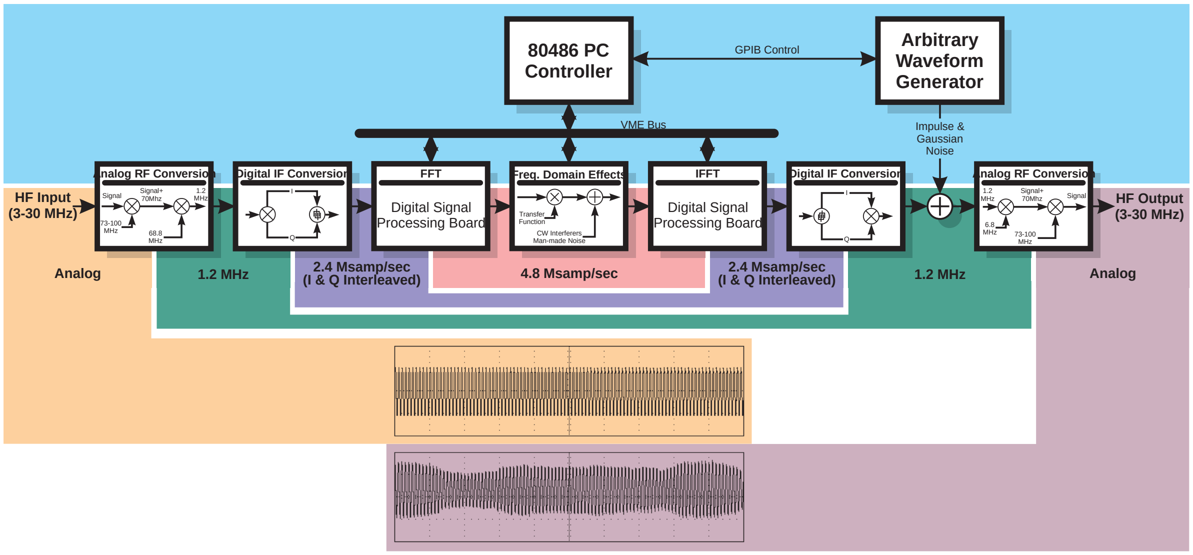

Figure 1. Block diagram of the wideband HF channel simulator.

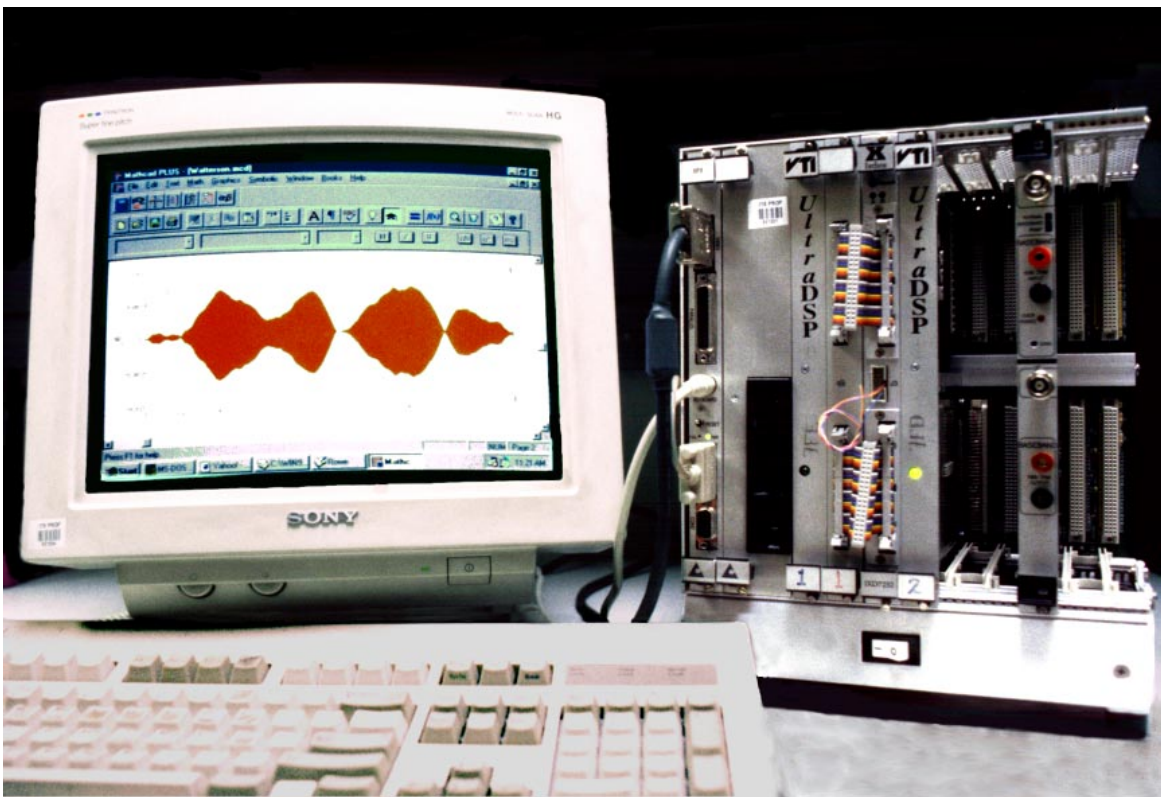

Figure 2. Hardware for the wideband HF channel simulator (photograph by F.H. Sanders).

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Advanced Radar Research

Outputs

- Performance prediction of radar systems.
- Development of radar algorithms for a wide array of applications.
- Radar simulation test bed for various systems.

The Institute is involved in research related to radar systems simulation and algorithm development. In this effort we are developing a radar simulation and performance prediction test bed (Figure 1). This test bed allows the radar system, the propagation channel, and the scattering object to be modeled, which then allows for performance prediction and algorithm development. Such a test bed is general enough to handle a wide array of radar applications. This past year our efforts concentrated on military radars used for target identification, and meteorological radars for determining wind speed.

There is a need in the military to identify a radar target (e.g., a ground vehicle, a ship, or an aircraft) from the target's scattered radar signature. The performance of signal/image-processing algorithms used to form radar target identification depends upon the radio propagation effects such as time-varying multipath, dispersion, noise, and attenuation. These propagation effects can seriously degrade the radar signature and significantly influence the target identification process. The Institute is investigating the use of minimum mean-square-error (MMSE)-equalizing filters on radar signatures to mitigate the effects of multipath and noise.

Figure 2 shows a typical multipath and noise environment that a radar is confronted with when trying to identify a ground vehicle. By knowing the statistical characteristics of the multipath channel, the MMSE filter can be used to recover the ground vehicle radar signature in a noisy, multipath environment. Figure 3 illustrates the improvement in the

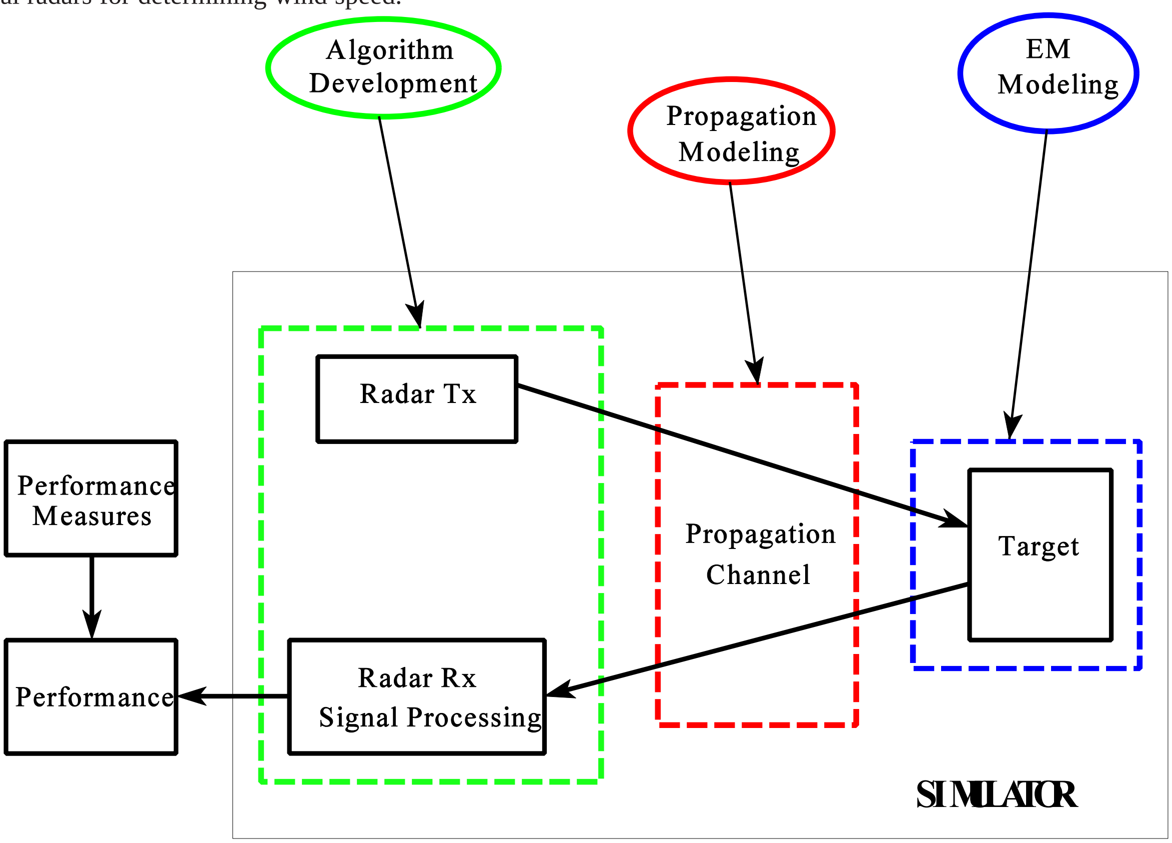

Figure 1. Radar simulation and performance prediction test bed.

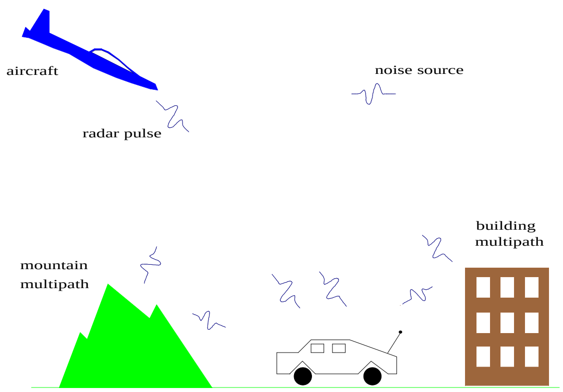

Figure 2. Radar target in a multipath environment.

radar signature if a MMSE equalizer filter is used for a two-path Rayleigh channel. Plotted in this figure is the mean-square-error (MSE), which is a comparison between the idealized radar signature (the signature of just the ground vehicle with no noise or multipath effects) to the realistic signature (the signature of the ground vehicle with noise and multipath effects). Small values of MSE indicate that the noise and multipath effects are mitigated, and the identification process is greatly enhanced.

In large-scale climate modeling, it is important to know the three-dimensional speed of the air mass in the lower boundary layer (from the surface to a height of 5 km). The wind speeds are used as initial starting points for these climate models. At the Institute we have been working with the National

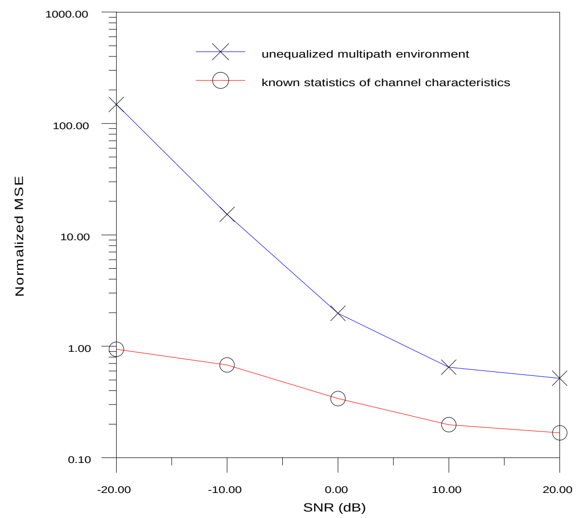

Figure 3 Normalized mean-square-error equalizer performance comparison.

Center for Atmospheric Research to develop theoretical scattering models for the atmosphere in the lower boundary layer. These models have allowed us to develop a 915-MHz radar system and algorithms for determining these boundary-layer winds. The system is presently being field tested and preliminary results look promising. These algorithms that were developed have the potential to yield frequent and accurate measurement data needed in the boundary layer for other important meteorologic parameters (such as momentum and temperature flux estimates).

Recent Publications

E.A. Quincy, R.A. Dalke, R.J. Achatz, C.L. Holloway, and P.M. McKenna, “Radar target image resolution enhancement via propagation channel equalization,” in *Proc. SPIE Radar Processing, Technology, and Application*, vol. 2845, Denver, Colorado, 1996, pp. 49-55.

R.J. Doviak, R.J. Lataitis, and C.L. Holloway, “Cross correlation and cross spectra in spaced antenna wind profilers part I: theoretical analysis,” *Radio Science*, vol 38, no. 1, pp. 79-84, 1996.

C.L. Holloway, R.J. Doviak, S.A. Cohn, and R.J. Lataitis, “Algorithms to retrieve wind from spaced-antenna wind profilers,” in *Proc. 27th Internat. Conf. Radar Meteorology*, Vail, Colorado, 1995, pp. 323-325.

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